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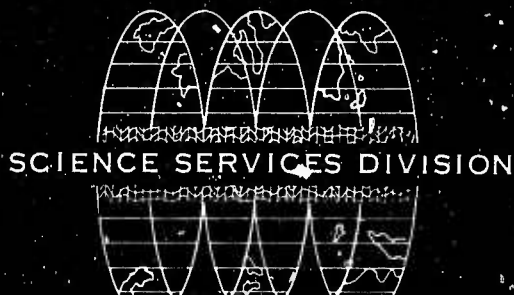
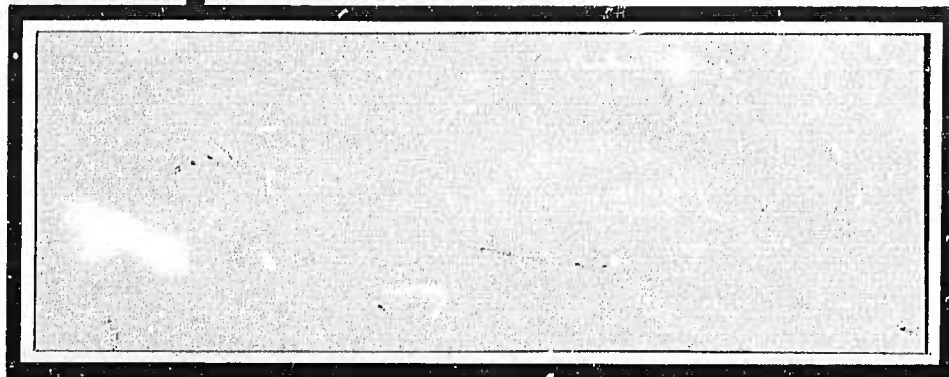
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Wash DC 20333

ADVANCED ARRAY RESEARCH

Quarterly Report No. 2

15 March 1967 through 14 June 1967

George Hair, Program Manager
Area Code 214, FL 7-5411, Ext. 441

TEXAS INSTRUMENTS INCORPORATED
Science Services Division
P. O. Box 5621
Dallas, Texas 75222

Contract No. F 33657-67-C-0708

Beginning 15 December 1966
Ending 14 December 1967

Prepared for

AIR FORCE TECHNICAL APPLICATIONS CENTER
Washington, D. C. 20333

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY
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ARPA Order No. 624
AFTAC Project No. VT/7701

5 July 1967



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SCIENCE SERVICES DIVISION

5 July 1967

Air Force Technical Applications Center
VELA Seismological Center
Headquarters, USAF
300 N. Washington Street
Alexandria, Virginia

Attention: Captain Carroll F. Lam

Subject: Quarterly Report No. 2 for period 15 March 1967
through 14 June 1967

Identification: AFTAC Project No. VELA T/7701
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ARPA Program Code No.: 7F10
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Contract Number: F 33657-67-C-0708
Effective Date of Contract: 15 December 1966
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Project Manager: George Hair
Area Code 214
FL 7-5411, Ext. 441

WORK PROGRESS

Progress during the second quarter is presented in this report by principal tasks. Areas of current investigation and plans for the third quarter are also presented.

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Task A

Using an ensemble of seismic array network data to be furnished by AFTAC, investigate bodywave noise on a coherent worldwide basis. Investigate interarray equalization problems. Study methods of combining the subarray output for network signal extraction. Investigate the capabilities of a worldwide network for resolving events closely spaced in time and space.

Data required for the network signal and noise studies under Task A are routinely received from SDL. The data are digitized from FM magnetic tape recordings, demultiplexed and reformatted for input to IBM equipment by SDL. DAC playbacks of the digitized records are also being provided by SDL. A new IBM 7044 program has been written and checked out which provides translation of the data into acceptable format for use with existing 7044 software. All digital tapes received from SDL to date have been satisfactorily translated with this program.

Data for six events and five noise samples have been received from SDL, with part of the ten requested stations for each event. The remaining nine events have been requested; and in addition, long-period data sampled at a 2-sample/sec rate have been requested for these events. Appropriate long-period and short-period calibrations have also been requested. Instrument response curve and array configuration information have been obtained and when further information pertaining to SDL filter response curves is received, all noise spectra will be converted to units of absolute ground motion. Meanwhile, analysis of calibration data already received is underway.

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Long-period data have been requested for two noise samples for which short-period data are already available. These data will be analyzed to determine whether long-period or short-period data are more suitable for noise characterization (i.e., study of high-velocity noise) at the network level. Additional noise sample requests are withheld pending the results of this evaluation.

An initial analysis of the noise data has been conducted to establish the seismic validity of the recorded data. Power density spectra of five noise samples have been computed for one channel each of all available stations. These spectra indicate seismically valid data up to 2.0 cps, with seismic noise 20 to 40 db above instrument noise in this band. Above 2.5 cps, most spectra exhibit narrow peaks probably related to instrument noise.

The various array configurations have been examined, and spectral windows and straight sum response for each array have been computed. A comparison of several methods for computing $f-k$ spectra is underway with the most suitable method subsequently used in the high velocity noise analysis.

Several techniques for velocity filtering are under consideration, and a comparison is being made of the relative effectiveness for signal extraction of straight sum, measured noise Wiener MCF and adaptive maximum likelihood filtering techniques. Primary emphasis is being placed on comparing the results of the adaptive approach to the standard methods in terms of performance and cost.

Although explosion data are required for an optimum investigation of interstation signal equalization, a preliminary investigation of equalization problems at the network level has begun using earthquake data only.

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Task B

Continue investigations of multi-element system studies to determine possible new combinations of sensors for noise reduction. Study methods of specifying, for given noise fields, the optimum multisensor system for noise reduction with the desired result a set of guidelines for array design. These guidelines should include, but not be limited to, the type of sensors required and, for an array, the size and geometry, subject to the constraints of practicability.

1. Program for Computing Theoretical Crosspower Spectra and/or Crosscorrelation Functions

Calculation of crosspower spectra from the solid cone model when horizontal seismometers are present has been found to be impractical in the framework of this program. It is possible to handle horizontal-vertical arrays for a model which appears in f - \vec{k} space as the surface of a cone. The solid cone model can then be approximated by a sum of a group of "surface-of-a-cone" models. This surface-of-a-cone model is to be distinguished from a degenerate case of surface wave propagation which assumes the same geometric shape in f - \vec{k} space. The first arises from compressional waves emerging from depth in a homogeneous halfspace. The waves are assumed to approach the surface with a single angle of incidence and are equally likely to come from any direction. The second model represents non-dispersive

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Rayleigh wave propagation which can exist in a homogeneous half-space. The second model as well as dispersive surface wave modes can be handled in the program.

Actual programming has been delayed pending completion of the IBM 360 installation. At this time, it appears that programming can begin in one month. Current effort is devoted to compressional wave models which arise in the presence of a layered media.

2. WMSO Noise Field Study

Analysis of the 1962 noise sample from WMSO has been completed. A special report describing the results of this study is in preparation and will be submitted during the month of July.

3. Augmentation of the WMSO Array and Horizontal Sensors

Based on the noise study results, a recommendation has been submitted for the emplacement of horizontal seismometers in the array at WMSO. This would permit experimental study of such sensors' value in the enhancement of body wave detection in the presence of surface wave noise. The relatively high level of surface wave energy at WMSO makes this a desirable location for the study.

Task C

Theoretically investigate methods of implementing continuously adaptive systems for application to time-varying noise fields and postdetection processing. Any system that can be simulated off-line should be evaluated using suitably characteristic data.

One way of viewing and perhaps developing the adaptive algorithm is as a classical iterative matrix inversion technique. The

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classical technique is modified by letting the matrix to be inverted, along with the solution, vary with time or iteration.

In solving for x in the system of equations $Ax + r = 0$, one may start from an approximate solution $x = u_t$ and proceed in the direction $r_{u_t} = A_{u_t} + r$ a distance $-\lambda r_{u_t}$ so that

$$u_{t+1} = u_t - \lambda r_{u_t}$$

For sufficiently small λ , $\lambda < 2/\lambda_{\max}^A$, the sequence u_t will converge to the solution x .

An autoregressive process of degree p can be represented by

$$X_{t+1} = \alpha^T X_t^{(P)} + \epsilon_{t+1}$$

where

$$X_t^{(P)} = (X_t, X_{t-1}, \dots, X_{t-P+1})^T$$

and α is a vector of fixed coefficients and the ϵ_{t+1} are independent $N(0, 1)$ variables. It is known that α satisfies

$$R\alpha = \gamma$$

where

$$R = E X_t^{(P)} [X_t^{(P)}]^T$$

$$\gamma = E X_t^{(P)} X_{t+1}.$$

At any point in time, a reasonable estimate of R , R_t , is given by

$$R_t = \mu R_{t-1} + (1-\mu) X_t^{(P)} (X_t^{(P)})^T$$

and, similarly,

$$\gamma_t = \mu \gamma_{t-1} + (1 - \mu) X_t^{(P)} X_{t+1}.$$

The update procedure for α is

$$\alpha_t = \alpha_{t-1} + \lambda (\gamma_t - R_t \alpha_{t-1})$$

and if we let $\mu = 0$, then the adaptive procedure we have been using follows.

One reason for looking at the adaptive algorithm from this point of view is that the same reasoning can now be applied to general signal extraction problems with arbitrary but unknown signal models. The general form of the equation to be solved is

$$(R_s + R_n) \alpha = \gamma_s.$$

The estimates of R_n and α are again indexed with t to get the adaptive algorithm.

$$\alpha_{t+1} = \alpha_t - \lambda d$$

$$d = [R_s + (R_n)_t] \alpha_t - \gamma_s.$$

There are numerous better ways to implement the above equations through approximations of R_g and these are under investigation at present. Also, it is clear that each of the classical matrix inversion iterative techniques corresponds to a potential adaptive processing algorithm.

Time Constant Considerations

It is desirable to be able to relate the parameter λ to the effective amount of data that is being used to design the set of filter coefficients at each point. Defining the sequence α_t^* by

$$\alpha_t^* = \alpha_t + \lambda_t' \epsilon_t X_t^{(P)}$$

where

$$\lambda_t' = 1 / [(X_t^{(P)})^T (X_t^{(P)})]$$

$$\epsilon_t = X_{t+1} - \alpha_t^T X_t^{(P)}$$

and α_t is the adaptive algorithm sequence of filter vectors, the sequence α_t^* is a "false gain" set of coefficients since

$$\epsilon_t^* = X_{t+1} - \alpha_t^{*T} X_t^{(P)} = 0.$$

However, the important thing to consider at present is that $\epsilon^* = 0$ implies that the time constant of the α_t^* with respect to the data is very short. Now consider the sequence

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$$\beta_t = \frac{\sum_{i=1}^{\infty} e^{-i/\tau} a_{t-i}^*}{\sum_{i=1}^{\infty} e^{-i/\tau}} = e^{-\frac{1}{\tau}} \beta_{t-1} + (1 - e^{-1/\tau}) \alpha_{t-1}^*$$

$$= \beta_{t-1} + (1 - e^{-\frac{1}{\tau}}) (\alpha_{t-1}^* - \beta_{t-1})$$

and it follows that β_t is the α_t defined by the adaptive algorithm

$$\lambda = (1 - e^{-1/\tau}) \lambda' = c \lambda'.$$

The time constant of the sequence α_t with respect to the data is therefore taken to be τ so that an "equivalent" boxcar section of data of length N is given by

$$N = (2-c)/c.$$

Task D

Investigate the effects and methods of reducing locally generated noise. The effects of such non-plane wave fields on multichannel filter design should be evaluated.

Adaptive processing of four sections of seismic multichannel data has been completed and a report of the results is in progress. At present it appears that adaptive prediction and adaptive signal extraction by maximum-likelihood filtering can be performed to almost duplicate the Wiener results for actual seismic

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data. In addition to being logically simpler to implement and less expensive, the adaptive approach appears to be effective in processing time-varying data.

No further work on near-array noise source problems has been done. Work was begun in June that makes use of programs, data, and experience accumulated in the work performed under Task C.

Task E

Continue studies of the instrumental equalization problem. Apply any new techniques available for studying instrumental equalization and evaluate the effectiveness of such techniques.

1. Statistical Noise Prediction

Signal extraction for a p-channel array frequently reduces to a noise estimation problem (maximum likelihood processing, for example) in which the noise crosscorrelations are estimated to determine an estimated-filter which could be used, for instance, to predict the noise on one channel from the noise on the other $p-1$ channels. The performance (mean-square prediction error) of such estimated-filters has been compared with the optimal Wiener filter error. The ratio of the estimated-filter's performance to the optimal filter performance is independent of the true channel crosscorrelations. Thus, the degree of channel correlation does not affect the relative performance of the estimated-filter.

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Similarly, the ratio of the estimated-filter's performance on the design points to the optimal Wiener error is independent of the channel crosscorrelations. Thus, the relative false gain for a highly correlated array is no worse than for a less correlated array.

If the noise is assumed Gaussian, the statistics of these invariant ratios can be determined. Such calculations tell the designer how well the estimated filter can be expected to perform. For example, a 12-channel filter based on 90 independent samples will perform within 1 db of the optimal (but unknown) Wiener filter with 99 percent confidence. Such computations are extremely useful in determining how many samples are needed to achieve some desired relative performance or in evaluating the performance to be expected from an existing system.

A special report which derives and explains these results is being prepared. Future effort will be devoted to extending these results to other related multichannel array problems.

2. Long-Noise Sample Study

Thirteen noise samples, from 1 to 4 hours long, have been selected initially from LASA Develocorder film recorded in December 1966 and April 1967. Playbacks of two of the better samples are being requested to satisfy data requirements. A five to six hour noise sample is still desired and will be obtained if it becomes available.

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11. SUPPLEMENTARY NOTES - - -		12. SPONSORING MILITARY ACTIVITY AFTAC Washington, D. C. 20333	
13. ABSTRACT Progress during the second quarter, present effort and plans for future work in the areas of network studies, multisensor arrays, continuously adaptive filtering, near-array noise sources, and intra-array equalization studies are presented.			

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14.

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